Development of Martian Regolith Simulants for Exploration of *In Situ* Resource Availability and Potential:

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Introduction: Data obtained from Mars Global Surveyor (MGS) and Mars Reconnaissance Orbiter (MRO) has vastly increased knowledge of Martian surface mineralogy [1-3]. The most abundant phase remains basalt; however, the nature and extent of aqueous and other altered phases is better established. As such, the need for regolith simulants that reflect the heterogeneity of the Martian surface chemically and mineralogically has come into play [4-6].

Currently broadly available simulants reflect the chemical and mineralogical average of global Martian surface dust and fine-grained regolith [4-5]. Though this fine-grained, windblown regolith is relatively homogenous on a global scale, the regolith not transported globally by wind may vary considerably [2, 4-6].and as a whole is not homogeneous. The goal of this study was to create multiple simulants that better represent the variability of Martian regolith based on current understanding of the chemistry and mineralogy of certain deposit types found on Mars [1]. These simulants will be used to explore the potential fertility and toxicity of *in situ* Martian regolith. Such information is key to developing concepts for the exploration and potential colonization of Mars.

Methodology: To produce simulants, a combination of synthetic and field-collected samples have been obtained. These samples will be combined to form five different simulants assemblages. These include: 1. Basalt-type (unaltered), 2. Sulfate-type 3. Phyllosilicate I-type, 4. Phyllosilicate II-type, and 5. Carbonate-type. These components will be combined in appropriate concentrations based on data from Mars Curiosity Rover, MRO and MGS missions [1-3], and Earth-based Martian analogs [7-9] (Table 1). The resulting simulant mineral assemblages will be treated to eliminate organic matter and sterilized. The simulants will be further examined using X-ray diffraction Rietveld analysis (XRD), X-ray Fluorescence (XRF), and imaging spectroscopy. This analysis will help to refine simulants and ensure that they adequately represent current understanding of Martian chemistry and mineralogy for the intended application.

Simulants: The five simulants broadly represent various geologic provinces on Mars [1].

Regolith 1: Basalt (unaltered). The basalt (unaltered) simulant represents deposits that have not been exposed to extensive aqueous alteration. Though much focus has been placed on aqueously altered deposits, much of the surface is relatively unaltered. It is an important component to consider in the use of regolith as an *in situ* material as this may be among the more widely available materials. The Rocknest sample collected by the Curiosity Rover represents a type location for this simulant [7]. Components include fresh basalts collected in the field, volcanic glass, and sulfate and perchlorate salts (Table 1).

Regolith 2: Sulfate. The sulfate simulant reflects the mineralogy of sulfate-rich deposits found in Valles Marineris, Terra Meridiani and Aram Chaos [1-3]. Relevant for understanding the aqueous history of Mars during the late Noachian and Hesperian. This is a somewhat common deposit type and is likely to be readily available for *in situ* use. The components of the simulant include non-fresh basalts collected in the field, copiapite (polyhydrated sulfate) collected at an acid mine drainage site, iron oxides, and sulfate and perchlorate salts (Table 1).

Regolith 3 and 4: Phyllosilicate I and II. A variety of phyllosilicate deposits are found on Mars associated with different formation processes [1-3, 10]. These are the most common type of aqueously altered deposit and important for understanding the aqueous history of Mars during the early Noachian. Phyllosilicate I represents deposits rich in Fe/Mg smectites found in a variety of Noachian terrains thought to be associated with shallow or surficial weathering [1, 10]. The components of Phyllosilicate I include non-fresh basalts, nontronite, and sulfate and perchlorate salts. Phyllosilicate II is also rich in Fe/Mg phyllosilicates representing deposits associated with low-temperature hydrothermal activity. The components include non-fresh basalts, nontronite, and chlorite (Table 1).

Regolith 5: Carbonate. This simulant represents carbonate deposits found on Mars. This is the least common of the represented deposit types, but very relevant in understanding Mars past geochemical conditions [8-9]. The Isidis basin is the type location for the carbonate simulant [1-3]. The components include non-fresh basalts, magnesium carbonates, olivine, and nontronite (Table 1).

Future Goals: The goal of this study is to create multiple simulants that will be used for future work in exploring the use of Martian regolith as an *in situ* material for planetary exploration. The most relevant and reproducible simulants will be used in plant growth experiments that seek to address some of the challenges faced in supporting a manned mission to Mars. The ultimate goal being to use simulants to address issues of toxicity and fertility of Martian regolith and understanding potential for past habitable environments on Mars.

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Table 1: Martian Regolith Components

	Components	**Regolith 1: Basalt (unaltered)**	**Regolith 2: Sulfate**	**Regolith 3: Phyllosilicate I**	**Regolith 4: Phyllosilicate II**	**Regolith 5: Carbonate**
Mineralogy	Basalts and Primary Silicates	Fresh basalt[1]	Non-Fresh basalt[2]	Non-Fresh Basalt[2]	Non-Fresh Basalt[2]	Non-Fresh Basalt[2] Olivine[3]
	Phyllosilicates	-	-	Nontronite[2,3]	Nontronite[2,3] Chlorite[3]	Nontronite[2,3]
	Sulfates	-	Copiapite[4]	-	-	
	Carbonates	-	-	-	-	Magnesite[3]
	Amorphous	Volcanic Glass[1] and/or Nano-phase ferric oxides[4]	Hydrated silica[3] and Nano-phase ferric oxides[4]	Allophane[3] and/or Hydrated silica[3] and/or Nano-phase ferric oxides[4]	Nano-phase ferric oxides[4]	Hydrous magnesium silicates (Deweylite)
	Salts	Anhydrite[5] Perchlorate[5]	Anhydrite[5] Perchlorate[5]	Anhydrite[5] Perchlorate[5]	Anhydrite[5] Perchlorate[5]	Anhydrite[5] Perchlorate[5]
	Iron Oxides		Hematite[3,4]			
Mars Type Location		Rocknest: Gale Crater	Valles Marineris, Terra Meridiani, Aram Chaos	Jezero Crater, Mawrth Valles, East Nili Fossae	Noachian Highlands, Walls of Nili Fossae and Valles Marineris	Isidis Basin
Approximate Ratios		68% Primary Minerals 30% Amorphous 2% Salts	48% Primary Minerals 20% Sulfate 30% Amorphous 2% Salts	48% Primary Minerals 20% Phyllosilicate 30% Amorphous 2% Salts	38% Primary Minerals 30% Phyllosilicate (clay and chlorite) 30% Amorphous 2% Salts	38% Primary Minerals 30% Carbonate 30% Amorphous 2% Salts

[1]Collected in New Mexico, [2]Nontronite containing-Basalt collected in Eastern Washington, [3]Obtained from University of Georgia, [4]Collected from Graves Mountain, Georgia, [5]Obtained from Fisher Scientific or other reputable facilities